SOIL-MORPHOLOGY IN THE STUDY OF CLIMATE CHANGE IN A SEMI-ARID REGION OF NORTHWESTERN IRAN

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Abstract

In the past few decades, changes in climatic conditions, particularly in (semi-) arid regions, are charged on "global warming", and held responsible for the shortage of water. In a study in northwestern Iran, geopedologic investigations, supported by soil micromorphological study and some archaeologic data, were projected in the historic framework to reconstruct landscapes, since several millennia, through which changes of climate could be deduced. The occurrence of a vast layer of travertine, formed around 27,000 years B.P. in a rich karstic environment, coated by an organic matter containing layer, with some rancienite mineral, dated back from 13,000 B.P., implies a humid environment, corresponding with the uppermost Wűrm, a pluvial period.

The geopedologic surveys supported by soil micromorphology revealed that between 6,000 and 2,600 years ago the area was subject to cycles of erosion and sedimentation leading to the formation of glacis. An arid type of climate characterized by the alternation of wet and dry periods is also supported by the occurrence of petrocalcic and argillic horizons. Although the climate has further turned dryer, cultivating rice, tobacco and cotton, which is said to have been stopped a few centuries ago, implies a wetter condition than today.

The study concludes that the change in soil moisture regime (aridification) has never been as degrading as it is today, due to the over-exploiting of the non-renewable fossil groundwater.

Keywords: Hamadan, Sharra, Iran, Multidisciplinary, Geopedology, Micromorphology, Global warming, Aridification

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1. Introduction

In the last few decades, changes in climatic conditions, particularly in the (semi-) arid regions, are often charged on the global warming, and held responsible for the shortage of water. Fortunately, media deal intensively with the issue (https://en.wikipedia.org/wiki/Paris_Agreement), which might help amplify its vitality in our life. Though, many scientists (geologists, geographers, climatologists) have absolutely no doubts on the global warming, there are "non-believers" who believe that this is all (only) the result of human activities, e.g., CO2 release.

In the past decades, several studies on paleoclimate and climate change in the Middle East have been published, that are also available online (Fisher, 1968; Zohary, 1973; Butzer, 1983; https://www.gfz-potsdam.de/en/section/climate-dynamics-and-landscape-evolution/projects/palex-paleoclimate-research-in-the-middle-east/; https://pdfs.semanticscholar.org/978c/ea666c62e2ec99c760fe89ef875b0c3707ef.pdf; http://siteresources.worldbank.org/INTLEBANON/News%20and%20Events/22651160/WB_newsletter_lowres_CC_En.pdf).

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This work occurs within the auspices of a larger project, a multidisciplinary study to evaluate the sustainability of the integrated soil and water management in the traditional and modern (semi-mechanized and mechanized) agricultural systems, in a semi-arid region of northwestern Iran. To prepare the geopedologic map as the basis for such a study, soilscapes were studied, for which many soil profiles in the delineated geopedolgic units were examined. Although the change of climate was foreseen as a component of the study, but before touching on this component, the geopedologic study pulled us to it. In other words, the study of the soilscapes became the entry to the interdisciplinary study, leading to set up the methodological approach, where soil micromorphology, clay mineralogy, archaeology, and history were supporting agents in reasoning on the change of climatic conditions and land use, and its relationship with aridification. Aridification being the changes of soil moisture regime towards an increasing soil aridity, caused by disturbances in soil/topography/vegetation/climate system. Aridification announces a worsening of the biophysical conditions. In the last few decades, almost everywhere within the arid world, where water is scarce, the non- renewable fossil groundwater is aggressively extracted through deep wells, which has caused the drop of the groundwater table depth leading to drying up of many traditional underground irrigation tunnels (ghanats), and to aridification (Farshad, 1997; Farshad and Zinck, 1998).

2. Methods and materials

2.1 Description of the area

To comply with objectives of the study, as a whole (Farshad, 1997), a few areas were selected in Hamadan-Bahar, Sharra, Kashan and Yazd, to represent the climatic conditions in the (semi-)arid Iran (Fig.1). In the present paper only the first two, i.e., Hamadan-Bahar and Sharra areas, hereafter be referred to as the Hamadan-Komidjan area will be dealt with. This is an historically important area in Iran, as it has been inhabited during the Medes (625-336 B.C.). The name Hamadan, written in diverse ways, has been mentioned in several ancient scripts and epigraphs. In an epigraph related to Tiglath-Pileser, one of the Assyrian kings from the eleventh century BC, the name *Hamadana* is reported. According to Herodotus, who uses the name *Hagmataneh*, the town has been built by the first Median king around 650 years BC. Whatsoever the correct foundation date might be, the crucial point, supported by historical documents, is that this area was known for its agricultural potential despite its semiarid climate.

Fig. 1: The whole area under study, including Hamadan-Komidjan area

2.2 Physiography

The study area can be divided into two sub-areas, namely the Dasht-e-Hamadan-Bahar, at the foot of the Alwand pick, and the Dasht-e-Sharra, the area stretching along the Sharra river valley (Fig. 2), roughly separated by a low mountain (Mo1 in Fig. 3).

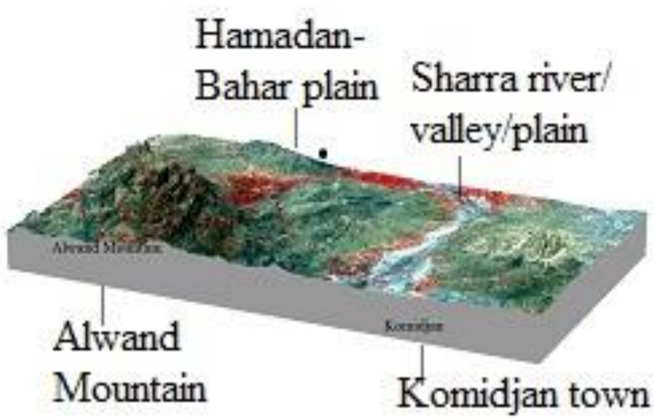

Fig. 2: The study area (DTM)

The Hamadan plateau (1750 m asl.) is located at the foot of the central Zagros mountain range, with its peak “Alwand” (Fig. 2). Following the geopedologic approach to soil survey (Zinck et al., 2016), mountain (Mo), hilly landscape (hilland) (Hi), piedmont (Pi), and valley (Va) are distinguished as the main units (landscapes) in the study area (Fig. 3).

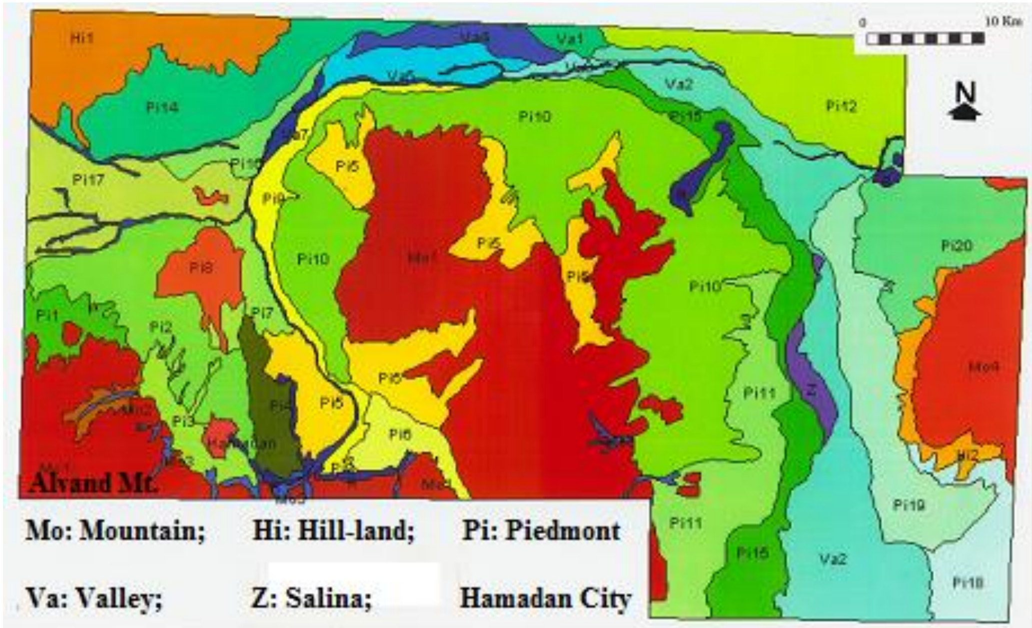

Fig. 3: Geopdologic units

The soils (Fig. 4) are classified according to the USDA Soil Taxonomy (1998), and distribute well, following the physiographic conditions. Very shallow rocky soils of the barren mountains and hills (Entisols) progress down-slopes to medium- textured and deeper soils (mainly Calcic Xerepts, also Petrocalcic Xerepts and some Calcixeralfs) on the dissected upper glacis. These are, then followed on the lower glacis and finally in the valley by finer textured and deep soils (Typic and Cacic Xerepts). The soils included in the Calcic and Typic subgroups have also a weakly developed fluventic character. Considering that in the Keys to Soil Taxonomy, the Fluventic subgroup of the Xerepts is listed before the Calcic subgroup, many soils that were weakly fluventic are thus classified as Fluventic, although they have also a calcic horizon. Because of their large extent, Calcic Xerepts were classified at the family or , in some cases, at the phase level.

Left: stratified profile (Fluventic subgroup of Xerepts); Right: soil with Salic horizon

 Profil F11 (columnar structure)	 Columnar structure is visible on the soil surface

 Profile FA24	 An example of the relic in FA24

Fig. 4 : A few examples of the soil profiles in the study area

The soils of the low-lying areas of the Sharra valley, mainly derived from sedimentary and often gypsiferous rocks, are salt-affected (Salids and Natrixeralfs). In general, the soils of the study area are calcareous and have a low organic matter content, alkaline reaction (pH varies from 7.5 to 8.5), with calcium carbonate accumulation somewhere in the upper 150 cm of soil, medium to fine texture and low biological activity.

2.3 Climate

(a) Precipitation: The average annual precipitation for a period of 20 years is about 300 mm, most of which fall during the period of December to May, with a maximum as snow in January (about 45 mm) and as rain in May (40 mm). Snow lies 6-8 months in the mountainous parts. From the total precipitation, 40-45% falls in winter, 30% in autumn, 25% in spring and 1-5 % in summer. The mean annual precipitation in the higher altitudes is about 100 mm more as compared with lower located stations (Salehi, 1994).

(b) Temperature: The mean monthly temperature in the Hamadan-Komidjan area varies between -5 °C in January and 24°C in June, with an annual mean of 10 °C. The hottest month is July and the coldest months are January and February. A mean maximum temperature of 34.5 °C occurs in July and a mean minimum temperature of -9.5 °C in January.

(c) Evaporation: The average annual evaporation from a class A pan for a period of 20 years (1964-1983) is 1870 mm. The highest evaporation takes place in July with 300 mm, while the lowest value is 13 mm in January.

(d) Relative humidity and wind speed: The mean annual relative humidity is about 55%. Relative humidity drops from June to October, with a lowest value of 33% in July, while it is high from December to March, with a highest value of 80% in January.

(e) Soil climatic regime: The soil moisture regime is (dry) xeric, and the temperature regime is mesic (Banaei, 1998; van Wavanmbeke, et al.,1986).

2.4 Water availability

Availability of water depends on the amount of precipitation, which varies within each year and from year to year, and on the groundwater recharge, but also on the way people use it. Estimation of available water is often difficult, especially if the concerned area is only a part of a watershed (basin).

The water balance for the Hamadan- Bahar area and a part of the Dasht-e- Sharra were established (Abdi, 1994; Salehi, 1994). The total water demand, including domestic uses, crop water needs, industrial and livestock consumption, amounts to 380 Mm^3 for the Hamadan- Bahar area. The available water, including both surface and groundwater, was estimated 345 Mm^3. This makes a negative balance of 34 Mm^3 per year. In the same way, the water budget for a part of the Sharra area shows a deficit of more than 120 Mm^3. For instance, in the village of Shirin-abad, an observation dug well showed a 13m drop of groundwater level in a period of six years, between 1986 and 1991.

According to Djamab (1990), in the Hamadan- Bahar area there are 1747 (semi-) deep wells, 158 ghanats (traditional underground tunnels; Farshad and Zinck, 1998) and 389 springs, with annual discharges of 285, 27.5 and 27 Mm^3, respectively. Thus, the highest discharge from the aquifers is through wells excavated in the recent years. This also holds true for the Sharra area. However, the rechargeability of the aquifers in the Hamadan-Bahar area is higher than in the Sharra area, because of the fractured Alwand granitic rocks, the long-lasting snow cover on the high Alwand peak and the permeability of the piedmont materials. The richest aquifers were those of the karstic limestone, which have dried because of intensive water extraction.

2.5 The methodological approach

Following the geopedologic study (Farshad, 1997), the following soil profiles in the key landscape units (hilland, various levels of glacis, river terrace, and depression) were also studied micromorphologically (Farshad et al., 1999). Prof. FA 22 (on an accumulation glacis near the village of Abaroo, south of the town of Hamadan (34°42′N 48°34′E), on derived material from schist); Pro. FA32 (on an accumulation glacis in the territory of Razan

(35°38´N 49°04´E), north of Hamadan, on calcareous material) and FA11(in the depression to the east of the town of Bahar, north of Hamadan) are the profiles in the Hamadan-Bahar area.

In the Sharra area, with a relatively drier climate, also a few profiles from different geopedologic units selected for the current study are: FA24 (a profile buried by archaeologically-rich deposits as an accumulation glacis to the west of the village of Shirinabad (34°54′N 48°27′E), in a site known as Shaltok-kari); FA18 (on one of the terraces of the Sharra river, a site next to the abandoned village of Hadjiabad; 34°51′N 49° 01′E); and the travertine site (FA18a), a flat field in the territory of the town of Gahawand.

All soil profiles are described using standards and terminology from the FAO (1990) and classified according to the USDA Soil Taxonomy (1998), sampled as well for physico-chemical analyses as for micromorphological investigations, using Kubiena boxes, mammoth size. To further fortify the investigation, in a few cases, X-ray diffraction was performed on clay-size fractions, in University of Ghent, Belgium. To frame relevant past events, that are partly extractable from the history, carbon 14 determination deemed necessary, and was carried out on soil and a few relicts, in C.I.O., University of Groningen, the Netherlands (Stuiver, 1993; van der Plicht and Mook, 1989).
Considering the objective of the present paper, next to soil (micro-) morphology, some other study results (Farshad, 1997) are presented too.

3. Results

3.1 Morphologic properties fortified by some laboratory studies

3.1.1 The following three sites (a, b, and c) are in the Dasht-e-Bahar-Hamadan (Fig. 2 & 3):

(a) FA22 (34°42′N 48°34′E): The soil is stratified and further characterized by a rather dark colour (10YR and 5Y 4/2), weak medium and fine sub-angular blocky structure and gravelly sandy loam and gravelly coarse sandy clay loam (Ap-Bw-C). The soil is classified as Loamy skeletal member of Typic Xerepts.

(b) FA32 (35°38´N 49°04´E) and FA02 (35°02´N 48°28´E): These two profiles are quite similar, although occurring in two different locations (Mech3 is in Razan district, and FA02 near the village of Djamshidabad, about 10 km north of Hamadan). The soil is very deep, brown (7.5YR) A and Bk horizons over yellowish brown (10YR) C. In profile FA02, at 130cm depth lies a brown (10YR 4/6) 2Bt, with broken thin clay skins. The dominant texture is clay loam and light clay, with one or two thinner horizons with gravelly texture. Structure is weak (in A) and moderate (in B) medium subangular blocky. The soil is classified as Loamy and Fine Calcic Xerepts.

(c) FA11 (34°54´N 48°27´E): This soil profile was studied in the Nahalestan depression (Fig. 1). This is the only area in the Hamadan-Bahar region where alkaline soils occur. Every year, people from the Torkashwand tribe, who have been granted the right to graze the area, move from the exhausted heights near the town of Kermanshah with their herds of sheep and goats. In the past, in winter time, the unused water of several ghanats was deviated and spread over this depression. The relics of a few artificial channels which led the excess water into the river are visible in the aerial photograph. In the centre of the depression, also relics of a castle on an elevated surface is visible. The artificial mound (the elevated surface on which the castle locates) has been so intensively excavated by locals that there is little left of it. Nobody remembers anything about the time that the castle was in use.

The soil is characterized by a Mollic-like epipedon over a rather thick brownish (7.5YR5/2) Bt with columnar structure (Ah-Bt1-Bt2-Bt3-BC), the rounded tops of which are visible on the ground surface (Fig. 4).

3.1.2 The sites (d, e, and f) that are studied in the Dasht-e-Sharra (Figs. 2 & 3):

(d) FA24 (34°55′N 49°05′E): This soil profile was studied in the glacis at the foot of the Agh-tappeh (white mound), in the Shaltook- kari area, which means paddy cultivation. No one could say something meaningful about the time when paddy was grown. Almost everybody mentioned that the tappeh is the remnant of a large settlement complex from the period of Solomon (over 900 years BC). Although this might not be literally true, it implies a distant past.

Several whitish low mounds occur in the area, which can be related to whitish upper Jurassic limestone. The area is a part of a bajada formed by coalescing alluvial fans, which originate from Jurassic and Oligo-Miocene formations. The Agh-tappeh and some other smaller mounds look like islands surrounded by fan deposits.

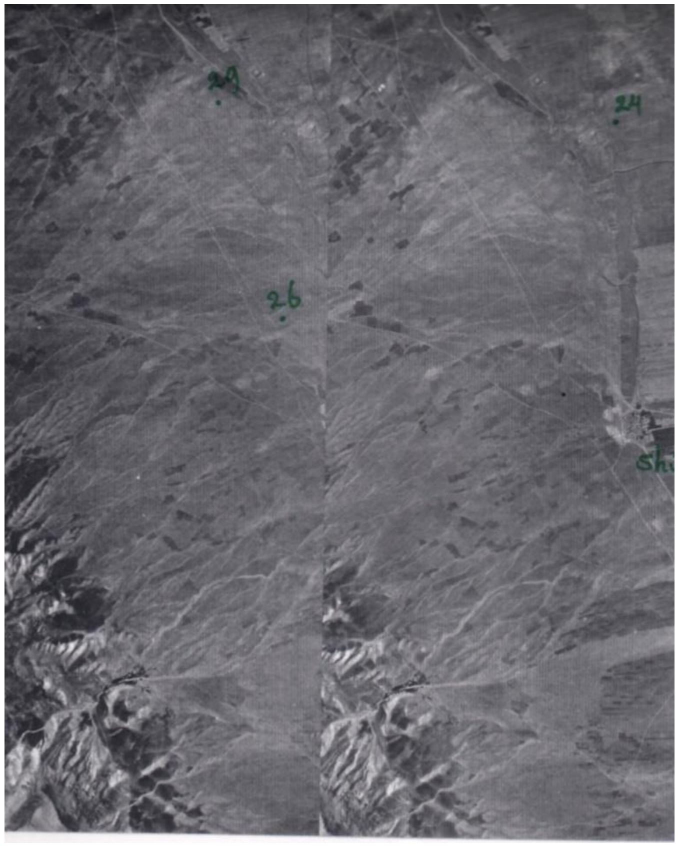

Fig. 5: Stereogram depicting the glacis, where FA24 occurs (sh=Shirin-abad)

The described soil profile is in the middle part of the bajada, at the foot of the mound, where the slope is nearly level. The soil is very deep (studied down to 195cm), dominantly brown (hue=7.5YR), except for the depth between 129 and 178cm (including Btb), where colour is greenish and/ or greyish olive (7.5YR 5.5/2 and 5Y6/2) (Fig. 5).

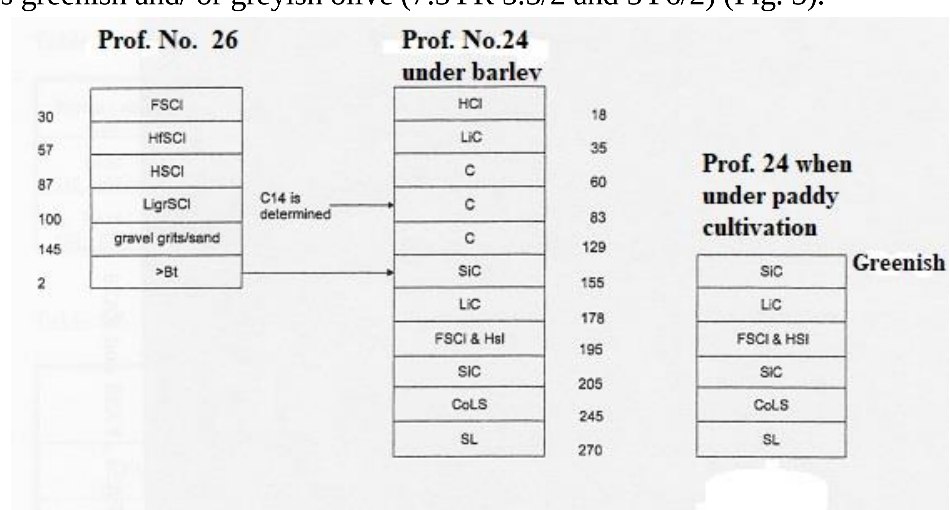

Fig. 6: A schematic pedo-stratigraphy, showing how soil profiles No. 26 (see Fig. 5) and No. 24 (present situation under barley, and before situation under paddy cultivation)

Texture of the thick Bt is dominantly clay. The texture of the stratified layers below the depth of 178cm (C) varies from sandy loam to sandy clay loam. Structure of the top 60cm is blocky, followed by prismatic to the top of the buried horizon. From 129cm downwards structure is described as massive, that is, in Btb and C (sub)horizons.

The archaeological features identified in the profile are as follows:

- Small pieces of pottery at two depths (60 -83 cm and 129 - 155 cm).
- A fragment of bone at the depth of 60- 83 cm, lying on a piece of thin clay pottery
- Two pieces of brick, one at the depth of 60- 83 cm and another one at160 cm depth.

In traditional agriculture, it is still a widespread practice to add sand or clay to make heavy topsoil lighter for growing vegetables or heavier for growing rice. Also, old roof debris (clay mixed with straw) are added to the topsoil to improve fertility.

(e) FA18 (34°51′N 49°01′E): The soil is moderately deep (at about 100 cm starts the lithic contact, an extremely hard rock), dominantly brown (hue=7.5YR), texture is silty clay to clay, and structure is prismatic parting to angular blocks, with common broken moderately thick clay skins on ped faces and in pores. Mottles are common distinct and concentrated in between 30 and 60cm depth. The soil profile, designated as A-Bt-Btg-Bt-R, is classified as clayey member of Vertic Natraqualfs.

(f) FA18a: On the left (Sharra) riverbank, to the east of the town of Ghahawand (34°51′N 49°00′E) a thick layer of travertine is exposed in a vast area with a poor vegetation cover, used as pasture (Fig.7).

Fig. 7: The exposed travertine

3.2 Micromorphology

The micromorphological properties of the key-profiles, such as FA22, FA32 and FA24, were constructive and/ or supportive (Bullock, et al., 1985). Regarding the occurrence of travertine, micromorphological study was constructive as it helped distinguish between petrocalcic and travertine and led to further mineralogical investigation on the black (organic) and whitish (calcitic) coat, where the mineral rancienite was identified. A very striking feature which helped distinguishing the travertine was the very large calcite minerals, related to karstic activity.

Soil morphology, that is, studying the buried horizons in several profiles, such as profiles FA31 (at ± 130 cm depth; dated ± 6000 yr. BP), and FA24 (at 130 cm depth; at ± 2600 yr. BP) indicated that glacis formation in the region was active before 2600 yr. BP, at least between 2600 and 6000 years ago. Stratification and fluventic property, which were also approved by micromorphological study supported the process of (accumulation) glacis formation.

Studying profile FA24 indicated that the layer at ±130cm, which has a reduced color and is associated with a lot of rusty coloured mottles (Fig. 11) was a paddy filed, about 2600 years ago. At this (130cm) depth micro-structure is weak subangular blocky, with curved planes, also channels, c/f 10µm 3/2, open porphyric, silt size fine material, which is crystallic. Quartz, mica, calcite, micritic limestone are forming the coarse fragments. Infilled vughs are crossed by new vughs and short plenary voids (See also Appendix).

The same profile also demonstrates a seasonally contrasted moisture regime in later ages, approved by the presence of prismatic structure (depth 60-130cm). At 35cm depth, in the same profile micro-structure is sub angular blocky, for a part vughy, c/f 20µm 3/2, open porphyric, with fine material as crystallic. Quartz, mica, calcite, limestone, shells of brachiopod (pectens) are the coarse fragments, and it is weakly mottled.

The occurrence of petrocalcic and argillic horizons in the soils of the area suggests a seasonal climate (USDA, 1975). Thin section from FA18, 3rd horizon shows strongly developed argillan and calcitan (Fig. 9).

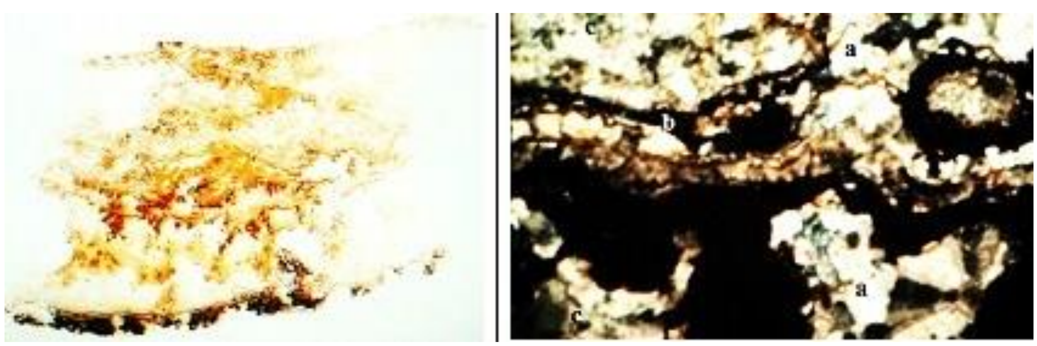

Fig. 8: Coated travertine specimen (left), micrograph of the thin section prepared from the specimen shown (right) under XPL (Crossed Polalizers) at magnification of x 2.5: a and c =Phenocrystals of calcite and b= dark layer containing organic material and some rancienite.

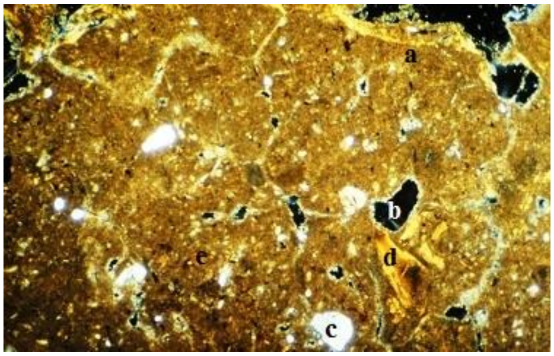

Fig. 9: Micrograph of the third horizon of profile FA18 clearly depicting clay skins under XPL, magnification= x2.5. a= striated b-fabric (both porostriated and granostriated); b= voids; c= mineral grains; d= laminated clay pedofeature; e= fragments of clay features embedded in the matrix.

The occurrence of considerable amount of un-weathered biotites in the soils of the area, particularly in the Hamadan-Bahar area, suggests a temperature regime not hotter than today, that is, mesic (Fig. 10).

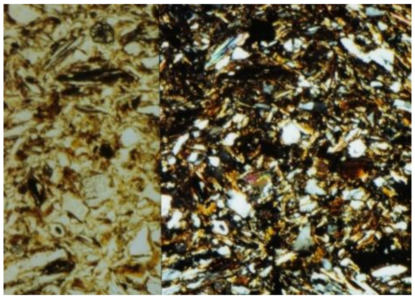

Fig. 10: An example of a soil where weakly to un-weathered calcite (=a) and biotite (b) clearly are visible in the micrograph

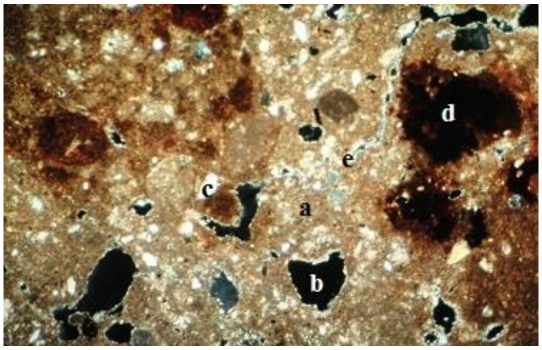

Fig. 11: Micrograph of Profile FA24, depth 130 to 140 cm under XPL, magnification = x2.5. a= groundmass (crystallitic b-fabric); b=voids (curved planes, chains and vughs); c= grains; d= distinct and prominent, clear palmate and digitate mottles; e= silt-infillings

4. Discussion and conclusions

The geopedologic surveys, supported by micromorphology, projected in history, reveal that the area was, for millennia, subject to cycles of erosion and sedimentation leading to the formation of extensive glacis. These plus carbon dating on soil samples of a few buried horizons indicate that the formation of piedmont in the region was active before 2600 years BP, at least between 6000 and 2600 years ago (Farshad, 1997; 2001). According to the archaeological findings, since some twenty-six centuries ago, rice, that can never be cultivated with the present climatic conditions, was grown in the *Shaltook kari* area, in the proximity of the present Shirin-abad village (Fig. 5).

Micromorphological study of the thin section of the buried horizon in Profile FA24, in the Shaltook kari area, agrees with a wet condition (Fig. 11). The occurrence of reddish mottles, with diffuse border, in an almost massive groundmass supports this idea too.

Historical studies revealed that alfalfa was extensively cultivated during the Medes, about twenty-seven centuries ago (Table 1).

Table 1: A brief overview of the agricultural background in Hamadan and the neighboring districts (for further details ref. to: Farshad, 2001).

Medes - Achamenids and the role of the Zorastrian religion (625 BC to 336 BC) Hagmataneh is believed to have been settled by both the Medes and the Achamenides. The Medes were good in agriculture and cattle raising. It is known that the best kind of alfalfa was grown in this period. The scientific name <u>Medicago Sativa</u>, a type of alfalfa grown in warm climates, and Medicago Falcata, a type of alfalfa grown under cold climatic conditions, refer to the Medes. The Achamenides took alfalfa seeds to Greece after they conquered that country. Obviously, the Zorastrian religion respected by these dynasties was of great influence. Avesta, the holy book of the Zorastrians clearly promotes cultivation by such statements as " bare land is occupied by evil forces". ***Parthians - Sassanids (248 BC to c. 600)*** The flourishment of irrigation is coined to the Parthians and the Sassanids, although not much of it is documented for the Hamadan- Komidjan study area.	***Mongol and Ilkhanid rule (13th century)*** In the 13th century the Mongol empire was established by Djengiskhan. Mongols were a group of horsemen tribes moving westward from Asia to Europe and raving everything on their way. In 1277, Bahar, north of the town of Hamadan, was a very green and developed place, when Holakoo's army rushed into it and destroyed everything. The ruins of the castle can still be recognized in a place called "Dowlar Ghalehsi". Many people escaped the unbearable situation, some even migrated to China. ***The Safavids (16th century)*** After the intermission caused by the Mongol invasion, the Safavids had to repair the damage. Shah Abbas paid due attention to agricultural development by constructing dams in different places.

Besides, in the period that Mesopotamia was a part of Persia, irrigated wheat and barley were produced too. On the other hand, the formation of a vast layer of travertine, around 27000 years ago (Farshad, 1997), is related to a wet period. The detailed investigations on the travertine layer revealed several facts, which help better understanding of the present landscape and the derived interpretations for agricultural aspects. The interior portion of the travertine (creme in colour) comprises calcite, some quartz and feldspars (Fig. 8). This, based on the results of carbon dating, goes back to 30440 years before present. The much thinner layer covering the creme-coloured layer, more whitish in colour, dates back from 27070 years BP. Finally, the dark coloured coat that covers almost the entire surface of the travertine layer comprises some calcite, much of goethite (FeOOH) and a seldom mineral type called rancieite [(Ca, $Mn^{2+})_{0.2}$ (Mn^{4+}, Mn^{3+}) O_2 $0.6H_2O$]. The dark coloured coat is about 1 mm thick and dates back from 13000 years before present, which corresponds with the uppermost Würm, in a pluvial period (Krinsley, 1970). Rancieite is not a commonly known mineral. It is believed that the mineral has a layer structure closely resembling that of birnessite, but with a different arrangement of the Mn octahedral framework as compared with that of the birnessite. The rather mixed and locally present coat on top of the dark coloured coating on the down-facing surface of the travertine layer there are some whitish half-ball-like in shape, which are light creme in colour and compose of calcite. This is also verified by the micromorphological study.

On the other hand, the presence of petrocalcic and argillic horizons suggests a seasonal climate, characterized by alternating dry and wet seasons. However, as travertine occurs at localities where karst springs were active its formation can be related to the presence of huge springs. Pirnahan was the last karst spring that dried about 30 years ago.

A large area in the Sharra valley is affected by salinity and alkalinity. In contrast, in the Bahar-Hamadan area, there are no saline soils and only a small unit on the lower piedmont (Nahalestan depression) is alkaline (profile FA11). Here too, the prism-like structure indicates a wet environment. In general, considering the extent of man-induced soil degradation, the Sharra valley was thought to have been occupied earlier than the Hamadan-Bahar area, probably because more water was available from the Sharra river and springs such as the Pirnahan.

The Hamadan- Bahar area is drained by the seasonal Absineh river, with a limited catchment area and very much depending on snow-melting water. It is also historically documented that a canal had to be established to convey water from the southern side of the Alwand mountain to build the palaces of the Hagmataneh. The fascinating Median capital of Ecbatana and its fabulous palaces were described by Herodotus and Polybios some 600 years BC.

The conclusion may be that the present dry xeric moisture regime was wetter in the past, however not ustic. On the other hand, combining the occurrence of travertine in the present study area with some earlier studies in Quaternary geology of Iran, reveals that during Würm these areas were peri-glaciated. Evidence of glaciation (as snowline/ -depression) in the Würm is recorded in both the Zagros and the Alborz mountain ranges, for instance in northern Kurdistan and in the Persian Azerbaijan (Seidan, 3615m.; Sabalan, 4812; Sahand, 3690m.). The snowlines locate almost always in higher altitudes than 3500 m asl (Butzer, 1964). In contrast, in the peri-glaciated areas, evidence of mud-flows and other materials resulted from solifluction are reported. Fossil slope breccias, presumably related to solifluction, have been reported to occur at elevation of 2300 m. At Marivan (with an altitude of about 1300 meters) in western Iran, an ook-pistacio savanna dominant since about 13000 BP, which infers a Mediterranean climate type. From this, it can be concluded that in lower altitudes (e.g., 1300 m) local ecological conditions during the late Würm were like those of the present.

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Appendix:

Thin section of Profile :FA 24 Hor. : 35-45cm

A. Micro structure

Subangular blocky and for a part vughy (very comparable with the lower part of the thin section Mech32. Vughs and short channels, calcarous silt and fine sand size materials form the groundmass.

B. Matrix (groundmass)

C/F 20 μm 3/2 ; open porphyric.

1 - Fine material, yellowish brown silt size mineral material, crystallic b-fabric

2 - Coarse fragments
a - simple grains
- dominantly subangular quartz (20- 300 μm) 10%
- acicular-planar mica (20- 50 μm) 3%
- subrounded calcite (20- 50 μm) 5%
b - Compound grains
- subrounded limestone (20 -1000 μm) 20%
- brachiopodae (Pectens) shells 5%
C. Special features

5% palmated (in shape), with distinct clear boundary ferruginous mottles; reddish brown in colour, moderately impregnated.

Thin section of Profile: FA24 Hor.: 90-100cm

A. Microstructure

Prismatic to angular blocky with planar voids network (crossing horizontal and vertical voids). Voids are relatively fine (20- 250 μm). Some short disconnected channels.

B. Matrix (groundmass)

C/F 10μm 1/3 ; open porphyric.

1 - Fine material, yellowish brown silt size mineral materials, crystallic b-fabric

2 - Coarse fragments

a - simple grains
- subangular quartz (20- 300 μm) 10%
- acicular/ platy mica (20- 50 μm) 1%
- acicular plagioclase (20- 50 μm) 1%
- planar calcite (20- 100 μm) 5%

b - Compound grains
- subrounded limestone (20- 1000 μm) 10%

C. Special features

10% ferruginous mottles (convolute nodules); dark reddish brown, weakly to moderately impregnated, irregular morphology (palmate to digitate), with clear boundary, locally as coating on grains.

Thin section of Profile : FA24 Hor. : +130 cm

A. Micro structure

Subangular blocky (moderately developed in the upper parts and weakly developed in the lower parts of the thin section, which gradually integrading to vughy). Voids (mainly curved planes, also channels and vughs), form 10- 20% of the total void space as a proportion of the thin section. Channels are fine and short, and vughs are weakly developed.

B. Matrix (groundmass)

C/F 10 μm 3/2 ; open porphyric.

1 - Fine material; yellowish brown silt size material, crystallic b-fabric

2 - Coarse fragments
a - simple grains
- angular quartz (20- 300 μm) 5 - 10%
- planar mica (20- 50 μm) 1%
- elongated calcite (20-50 μm) 5%

b - Compound grains
- (sub-) rounded micritic limestone (20- 1000 μm) 10%

C. Special features

- 10- 20% brownish red (mixture of iron and organic matter) distinct and prominent, clear palmate to digitate mottles, moderately impregnated.

- silt-infillings: infilled vughs (500 - 2000 μm) with reddish brown homogeneous silt-size materials, locally with one or two fine limestone grains. The infilled vughs have abrupt to clear boundary and locally are crossed by new vughs and short planary voids.